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# Thrips As Vector of Tospovirus

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## Introduction

Thrips belongs to the insect Order Thysanoptera: Thripidae (Mound 1997). Adult thrips are slender and small insects (typically 1–2 mm in length), with two pairs of wings in the adult stage (Lewis 1973). Thrips are referred to as "fringe-wing" insects because their wings are long and narrow with a fringe of long hairs on both the front and hind wings (Fig.1). Adults of some species can have a micropterous form (reduced wing) along with the macropterous (winged) form (e.g., tobacco thrips, *Frankliniella fusca* (Hinds)) (Lewis 1973, Oetting *et al*. 1993). The mouth cone is asymmetrical and is oriented posteriorly on the lower side of the head (Lewis 1973, Heming 1993).

The parameters of life cycle of thrips are extremely variable from one species to another. Hence, as a general the most studied Tospovirus vector, *F. occidentalis* adults insert bean-shaped eggs into leaf, flower or fruit tissues (Hansen *et al*. 2003). The first instars hatch within 5 days and molt into second instars within a day at 30°C. Second instars develop into prepupae within 4 –5 days (Lowry *et al*. 1992). Late second instars usually fall into the soil and pupate, but some can remain on the plant (Broadbent *et al*. 2003). The nonfeeding pupal stage is mostly immobile and has distinct and well-developed wing pads (Lewis 1973). Adults emerge within 3 days at 30°C (Lowry *et al*. 1992). Thrips development is known to be dependent on temperature. Adult females can survive for 4 – 5 week at 30°C and oviposit 50 eggs (Reitz 2008). Fertilized *F. occidentalis* females are known to produce female biased sex ratios and unmated *F. occidentalis* females are known to produce male biased sex ratios (Lewis 1973, Moritz 1997). Thrips are known to feed by using their piercing and sucking mouth parts

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and consuming plant sap (Lewis 1973, Heming 1993). Such type of feeding often results in silvering and curling of leaves, followed by necrosis of plant tissue. Thrips feeding and oviposition can also result in injury to fruit (Childers and Achor 1995). Some thrips species e.g., FL flower thrips, *Frankliniella bispinosa* (Morgan), primarily feed on the floral parts such as petals and pollen, which results in spotting, deformation of flower buds and reduced fruit set (Childers and Bullock 1999). In addition to feeding, thrips also cause damage as transmitting the tospoviruses.

Tospoviruses belong to the sole genus *Phytovirus* and family Bunyaviridae. Tospoviruses are known to be exclusively transmitted by thrips belonging to the family: Thripidae and subfamily Thripinae. Members of the order *Bunyavirales* are generally enveloped viruses with at least three negative-sense single-stranded RNA genome segments designated as large (L), medium (M) and small (S). Out of the known 1,710 species of Thripidae only 14 thrips species are currently reported to transmit tospoviruses. Thrips are known to transmit tospoviruses in a persistent propagative manner (Ullman *et al*. 1997). Both larval and adult stages of thrips vectors can actively feed on virus infected host plants, but only early larval instars can acquire the virus and later instar larvae and adults can transmit the virus after a latent period (Wijkamp *et al*. 1996a, Ullman *et al*. 1997, Whitfield *et al*. 2005, Persley *et al*. 2006). Adult thrips can acquire tospoviruses, but they do not transmit them. This is presumably because of insufficient multiplication in the midgut, a lack of movement to salivary glands and a lack of multiplication thereafter. These are prerequisite for Tospovirus transmission (Wijkamp *et al*. 1996b). In addition, tospoviruses are not transmitted transovarially (Wijkamp *et al*. 1996a). Thus, each new generation of thrips vectors must acquire the virus as larvae. There are distinct associations between thrips species and their ability to transmit specific tospoviruses (Jones 2005). Tospovirus infection is known to induce a suite of symptoms on its host plants including leaf speckling, mottling, chlorotic, and necrotic lesions of various shapes, sunken spots, etches, ring spots, stunting, yellowing, and wilting. These symptoms are known to vary with the host plant species, cultivars, plant age, virus isolate and/or strain, and environmental conditions (Best 1968, Lublinkoh and Foster 1977, Murai 2000, Chaisuekul *et al.* 2003, Gitaitis 2009).

Tospoviruses are re-emerging as a global threat to food security due to the decreased efficacy of management strategies adopted for virus and vector control. The spread of thrips includes their ability to travel unnoticed in shipments of plants and plant products due, in part, to their small body size and concealed eggs in plant tissues and the ability for populations to develop insecticide resistance. There is a tight link between thrips development and virus dissemination in the insect and recent transcriptome studies point to stage-specific responses that coincide with localization of the virus in the insect body. Transcriptome sequencing of thrips vectors is leading to identification of virus-responsive thrips genes and possibly new targets to disrupt the virus transmission cycle. Accumulation of thrips-omics resources and advancements in functional biology tools will propel new and exciting molecular studies of thrips-tospoviruses interactions. Thrips-transmitted tospoviruses cause severe yield losses to several economically important crops worldwide.

Global trade and associated movement of plant materials across borders have introduced tospoviruses and their vectors into newer areas. Advances in serological and molecular techniques have also led to identification of new tospoviruses. This scenario has also initiated new vector-pathogen interactions between introduced and native thrips species and tospoviruses.

**Management:** Control of tospoviruses is equally challenging due to the capacity for rapid genetic change in virus populations because of genome segment reassortment and the common reliance on one source or single gene conferring resistance in cropping systems (Gilbertson *et al.* 2015). The need for innovative and durable control measures for this complex pathosystem has inspired research in molecular interactions between

**Table 1. Summary of thrips-*Tospovirus* associations that have been confirmed by transmission studies as of September 2010. The thrips species are ranked from highest to lowest based on the no. of virus associated publications currently available**

| Thrips species | *Tospovirus* transmitted | References on *Tospovirus* transmission |
|---|---|---|
| *Frankliniella occidentalis* | *Chrysanthemum stem necrosis virus* | Nagata and de Áévila 2000, Nagata et al. 2004 |
| | *Groundnut ringspot virus* | Wijkamp et al. 1995, Nagata et al. 2004 |
| | *Impatiens necrotic spot virus* | De Angelis et al. 1993, Wijkamp et al. 1995, Sakurai et al. 2004 |
| | *Tomato chlorotic spot virus* | Nagata et al. 2004, Whitfield et al. 2005 |
| | *Tomato spotted wilt virus* | Medeiros et al. 2004, Nagata et al. 2004, Wijkamp et al. 1995 |
| *Thrips tabaci* | *Iris yellow spot virus* | Cortês et al. 1998, Hsu et al. 2010 |
| | *Tomato spotted wilt virus* | Wijkamp et al. 1995 |
| | *Tomato yellow fruit ring virus* | Golnaraghi et al. 2007 |
| *Frankliniella schultzei* | *Chrysanthemum stem necrosis virus* | Nagata and de Áévila 2000, Nagata et al. 2004 |
| | *Groundnut ringspot virus* | Wijkamp et al. 1995, de Bordón et al. 2006, Nagata et al. 2004 |
| | *Groundnut bud necrosis virus* | Meena et al. 2005 |
| | *Tomato chlorotic spot virus* | Wijkamp et al. 1995, Nagata et al. 2004 |
| | *Tomato spotted wilt virus* | Wijkamp et al. 1995, Sakimura 1969 |
| *Frankliniella fusca* | *Tomato spotted wilt virus* | Sakimura 1963 Naidu et al. 2001 |
| | *Impatiens necrotic spot virus* | |
| *Thrips palmi* | *Calla lily chlorotic spot virus* | Chen et al. 2005 |
| | *Groundnut bud necrosis virus* | Lakshmi et al. 1995, Meena et al. 2005, Reddy et al. 1992 |
| | *Melon yellow spot virus* | Kato et al. 2000 |
| | *Watermelon silver mottle virus* | Iwaki et al. 1984 |
| *Scirtothrips dorsalis*[a] | *Groundnut bud necrosis virus* | German et al. 1992, Meena et al. 2005 |
| | *Peanut chlorotic fan-spot virus* | Chen et al. 1996, Chu et al. 2001 |
| | *Peanut yellow spot virus* | Gopal et al. 2010 |
| *Frankliniella intonsa* | *Groundnut ringspot virus* | Wijkamp et al. 1995 |
| | *Impatiens necrotic spot virus* | Sakurai et al. 2004 |
| | *Tomato chlorotic spot virus* | Wijkamp et al. 1995 |
| | *Tomato spotted wilt virus* | Wijkamp et al. 1995 |
| *Frankliniella bispinosa* | *Tomato spotted wilt virus* | Avila et al. 2006 |
| *Thrips setosus* | *Tomato spotted wilt virus* | Tsuda et al. 1996 |
| *Ceratothripoides claratris* | *Capsicum chlorosis virus* | Premachandra et al. 2005a,b |
| *Frankliniella zucchini* | *Zucchini lethal chlorosis virus* | Nakahara and Monteiro 1999 |
| *Frankliniella gemina* | *Tomato spotted wilt virus* | de Bordón et al. 1999 |
| | *Groundnut ringspot virus* | de Bordón et al. 1999 |
| *Frankliniella cephalica* | *Tomato spotted wilt virus* | Ohnishi et al. 2006 |
| *Dictyothrips betae* | *Polygonum ring spot virus* | Ciuffo et al. 2010 |

[a]Amin et al. (1981) reported *S. dorsalis* as a vector for *Tomato spotted wilt virus*, but later German et al. (1992) clarified that this previous report of a Tomato spotted wilt virus-like virus in India based on a nonspecific identification was actually *Groundnut bud necrosis virus*.

tospoviruses and their thrips vectors (Rotenberg *et al*. 2015, Schneweis *et al*. 2017, Shrestha, *et al.* 2017 and Montero-Astúa *et al*. 2014). This review highlights recent descriptions of virus dissemination in thrips and the vector response to tospovirus infection with a focus on the most globally pervasive thrips-tospovirus system, *Frankliniella occidentalis* and tomato spotted wilt virus (TSWV). Virus taxonomy has been adaptive in attempts to accurately classify the large numbers of viruses revealed by new generation sequencing technologies. New virus sequence data derived from diverse hosts are providing a more comprehensive view of the virome, including viruses that replicate in non-model insect.

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